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AFATL-TR-71-169
VOLUME II

CLOSE AIR SUPPORT MISSILE GUIDANCE AND CONTROL STUDY

VOLUME II. THREE-DEGREE-OF-FREEDOM SIMULATION

DEPARTMENT OF MECHANICAL ENGINEERING
THE UNIVERSITY OF FLORIDA

TECHNICAL REPORT AFATL-TR-71-169, VOLUME II

~~DECEMBER 1971~~

for Test & Evaluation

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AIR FORCE ARMAMENT LABORATORY

AIR FORCE SYSTEMS COMMAND • UNITED STATES AIR FORCE

EGLIN AIR FORCE BASE, FLORIDA

Close Air Support Missile Guidance And Control Study

Volume II. Three-Degree-Of-Freedom Simulation

J. Mahig

TEST + EVALUATION

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FOREWORD

This report was prepared by the Industrial and Experiment Station, Department of Mechanical Engineering, University of Florida, Gainesville, Florida, under Contract No. F08635-71-C-0073 with the Air Force Armament Laboratory, Eglin Air Force Base, Florida, during the period from 9 December 1970 to 9 December 1971. Lieutenant Robert J. Karner (DLWG) monitored the project for the Armament Laboratory.

The principal investigator for the contractor was Dr. J. Mahig.

This report consists of two volumes. Volume I is devoted to the Six-Degree-of-Freedom Simulation while Volume II is concerned with the Three-Degree-of-Freedom Simulation. This is Volume II.

This technical report has been reviewed and is approved.

Heyward H Strong

HEYWARD H. STRONG
Acting Chief, Air-to-Surface Guided Weapons Division

ABSTRACT

This report describes in detail a three-degree-of-freedom program which can be used to determine the trajectory and miss distance of a guided missile system. The options for the program are such as to permit variation of the aerodynamics, seeker, autopilot, actuator, and missile motor performance for the purpose of accurately simulating a given missile design and evaluating the effects of any changes in system parameters. Sufficient detail has been included in the text to minimize the effort needed to update or modify the program presented.

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SECTION I

INTRODUCTION

The purpose of the report is to describe in detail the equations used and the form required for the input data to a three-degree-of-freedom simulation of a laser guided missile system. The primary purpose of a three-degree-of-freedom simulation is to make possible the study of the characteristics of a given missile system quickly and economically. Since cross-coupling effects influence a missile's performance through the seeker, autopilot, and missile dynamics, any results obtained must be considered as preliminary until justified by a six-degree-of-freedom simulation.

Examples of some of the studies which can be usefully made are optimization of the seeker, autopilot gain, and noise sensitivity. The noise sensitivity studies include not only electronic noise but spot motion and signal loss simulation. Once the parameters for a given missile have been entered, it can be used efficiently even on a small computer since the program only requires 17,000 words of core.

The program for a specific missile is given in Appendix I. This program is made up of four parts: the main program and the subroutines DER, MODAMS, and GAUSS. The main program modifies input data to conform to program logic and maintains sole control for batch processing requirements. The subroutine DER retains control only over a given missile flight. The purpose of this routine is to determine the current value of the aerodynamic coefficients and angle of attack; provide limiters (e.g., fin deflection and electronic saturation); and determine the present value of the derivative of the state variables. The subroutine DER then updates the state variables by calling the subroutine MODAMS which integrates the entire system of equations using an Adams-Moulton predictor-corrector method with a Runge-Kutta start. The subroutine GAUSS is used by DER to generate a set of random variables which are used to determine the position of a laser spot and the apparent location of the target with respect to the missile. The routine is also used to determine pulse loss through the variable VLAZRP.

All the aerodynamic coefficients are either a function of Mach number or of the fin deflection. The aerodynamic coefficients used in this program are plotted in Appendix II. These plots are used to develop the aerodynamic coefficients as approximate functions of the dependent variable Mach number and fin deflection. The procedure makes DER compute much faster than would be possible through a table look-up procedure and need not detract from the accuracy.

SECTION II

STATE VARIABLES

A discussion of state variable techniques is given in many control theory books[1,2,3]. However, a discussion of these techniques is appropriate at this point since they are used in the program to determine the missile's flight path.

The equation of motion governing pitch of the missile is given below in the familiar form:

$$I_{yy}\ddot{\theta} = M_2 \qquad (1)$$

where M_2 is considered a function of time and the state variables. To convert this to state variable notation, the second order equation must first be converted into two first order equations. (This is also true for an n^{th} order system which, in order to be converted into the state variable form, must first be converted into n [illegible] order systems.) Equation (1) is converted through [illegible]owing definitions:

$$\dot{\theta} \equiv \theta_2$$

$$\dot{\theta}_2 \equiv M_2$$

Now, since M_2 is a function of θ and θ and t, then the system may be defined in state variable form as

$$\dot{\theta} = \theta_2$$

$$\dot{\theta}_2 = M_2(\theta, \theta_2, t).$$

This same process can be used for an n^{th} order system.

A list of the state variables and their derivatives in DER is given in Table I.

TABLE I. PROGRAM VARIABLE AND STATE VARIABLE IDENTIFICATION

	State Variable	State Variable Derivative
1.	X - Y(1,1)	$\dot{X}$ - YP(1,1)
2.	$\dot{X}$ - Y(2,1)	$\ddot{X}$ - YP(2,1)
3.	Z - Y(3,1)	$\dot{Z}$ - YP(3,1)
4.	$\dot{Z}$ - Y(4,1)	$\ddot{Z}$ - YP(4,1)
5.	λ_S - Y(5,1)	$\dot{\lambda}_S$ - YP(5,1)
6.	λ - Y(6,1)	$\dot{\lambda}$ - YP(6,1)
7.	δ - Y(7,1)	$\dot{\delta}$ - YP(7,1)
8.	$\dot{\delta}$ - Y(8,1)	$\ddot{\delta}$ - YP(8,1)
9.	$\ddot{\delta}$ - Y(9,1)	$\dddot{\delta}$ - YP(9,1)
10.	θ - Y(10,1)	$\dot{\theta}$ - YP(10,1)
11.	$\dot{\theta}$ - Y(11,1)	$\ddot{\theta}$ - YP(11,1)
12.	R - Y(12,1)	$\dot{R}$ - YP(12,1)
13.	ϕ - Y(13,1)	$\dot{\phi}$ - YP(13,1)
14.	ϕ_M - Y(14,1)	$\dot{\phi}_M$ - YP(14,1)

Note: State Variables R, ϕ, ϕ_M are the results of proportional guidance implementation. The implementation is assumed ideal.

SECTION III

SYSTEM EQUATIONS

3.1 Equations of Motion

The equations of motion for the three-degree-of-freedom simulation used in the program are developed as follows:

The forces in body axes -

$$F_1 = -(C_A + 2C_{A\delta}|\delta|)qS + TH$$

$$F_3 = -(C_{N\alpha}\alpha + C_{N\delta}\delta)qS$$

$$M_2 = (-C_{N\alpha}(X_{cp} - X_{cg})\alpha + C_{N\delta}(X_{cg} - X_c)\delta)qSd$$
$$-C_{M\theta}\theta(\rho V_A/4)Sd^2$$

Table II defines the relationship between the commonly used aerodynamic coefficients, used above, with the variable names used in the fortran program listing shown in Appendix I.

The equations of motion in the earth fixed coordinate system are:

$$m\ddot{X} = F_1 \mathrm{Cos}\theta + F_3 \mathrm{Sin}\theta$$

$$m\ddot{Z} = -F_1 \mathrm{Sin}\theta + F_3 \mathrm{Cos}\theta + mg$$

$$I_{YY}\ddot{\theta} = M_2$$

where the quantities α, V_A, and q are defined as follows:

$$\alpha = V_{ZA}/V_{XA} \qquad (\alpha < 15°)$$

$$V_A = \sqrt{V_{XA}^2 + V_{ZA}^2}$$

$$q = \tfrac{1}{2}\rho V_A^2 \quad ,$$

and the variables V_{XA} and V_{ZA} (the velocity along and perpendicular to the missile centerline) are given as:

$$V_{XA} = \dot{X}\ \mathrm{Cos}\theta - \dot{Z}\ \mathrm{Sin}\theta$$

$$V_{ZA} = \dot{X}\ \mathrm{Sin}\theta + \dot{Z}\ \mathrm{Cos}\theta$$

TABLE II. EQUIVALENCE OF AERODYNAMIC COEFFICIENT NOTATION

Aerodynamic Coefficient	Program Variable
C_A	CA
C_{A_δ}	DCA
C_{N_α}	CNA
C_{N_δ}	CND
$C_{M_{\dot\theta}}$	CMT
C_{M_δ}	CMD

Figure 1 and Table III respectively, contain the coordinate system used in the derivation of the equations of motion presented above and define those other terms used as necessary.

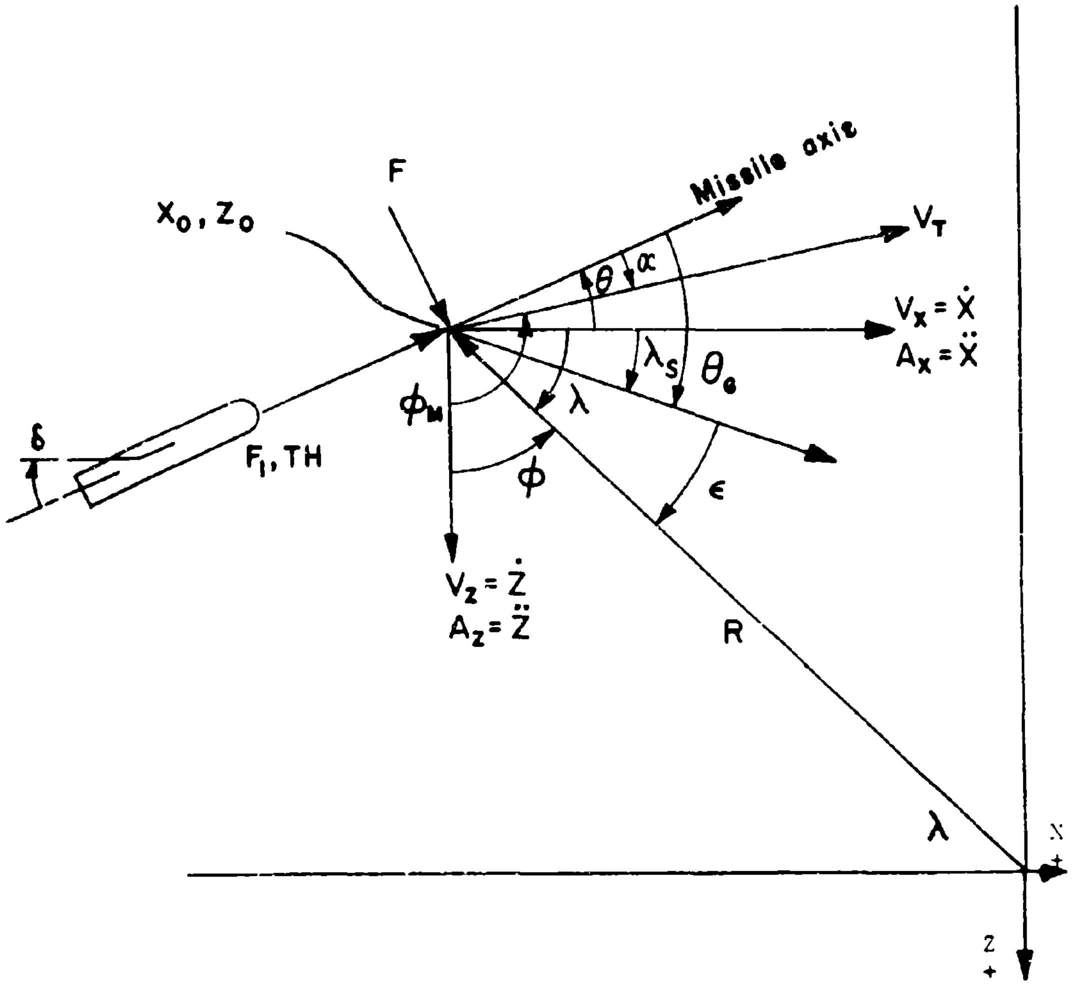


Figure 1. Coordinate System

TABLE III. VARIABLE LISTING

X	- Position of missile in X direction
Z	- Position of missile in Z direction
λ_S	- Line of sight of seeker
λ	- Line of sight of missile
δ	- Fin Deflection
θ	- Pitch of missile
t_g	- Guidance delay
m	- Mass of the missile
I_{yy}	- Moment of inertia
q	- Dynamic pressure
S	- Reference area
d	- Diameter of missile
ρ	- Density of sir (slugs per cubic feet)
TH	- Thrust force
g	- Gravity
V_{XA}	- Velocity along missile axis
V_{ZA}	- Velocity perpendicular to missile axis
V_A	- Total velocity of the missile
α	- Angle of attack of the missile
X_{cq}	- Initial location of the center of gravity (calibers) (Equivalent to missile diameters)
X_{cp}	- Location of center of pressure (calibers)
X_c	- Location of fin (calibers)

3.2 Seeker Equations

The position of the target is always assumed to be at the location of the origin of the coordinate system. Thus, the line of sight may be given as

$$\lambda = \tan^{1}(Z/X).$$

If the seeker is assumed to be a PLG seeker, then the variation of the seeker axis in terms of the missile orientation may be given as

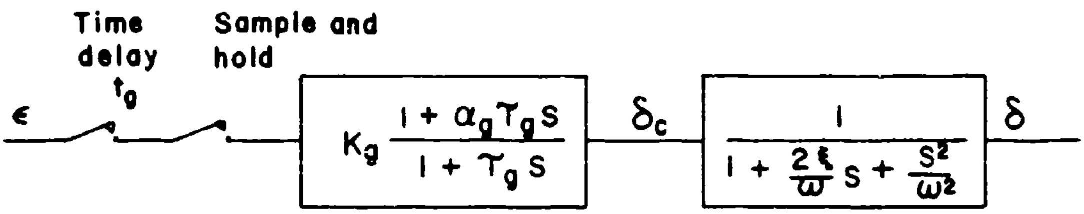
$$\lambda_S = -\theta(1 + \tau_S S).$$

The angle between the line of sight and the seeker axis may be given as

$$\varepsilon = \lambda - \lambda_S.$$

3.3 Autopilot Equations

The block diagram for the autopilot used in the program is given below in Figure 2.



K_g - 9.0 sec

T_g - .08 sec

α_g - 10.0 sec

t_g - .25 sec

ξ - .5

ω - 20 rad/sec

Figure 2. Autopilot Block Diagram

3.4 Nominal Thrust Profile

The initial thrust is

$$7500 \text{ lb}; \; 0 < t < 0.8 \text{ seconds}$$

which then linearly decreases to zero at 1.3 seconds.

3.5 Current Input Configuration

The input data for the missile configuration used is:

$$d = 0.416$$

$$S = 0.136$$

$$X_{cg} = 10.6 \text{ (initial)* [8.75 at burnout]}$$

$$X_C = 8.4$$

$$M = 4.21 \text{ (initial)* [3.48 at burnout]}$$

$$I_{YY} = 29.56 \text{ (initial) [25.04 at burnout]}$$

$$\tau_S = 5.0.$$

3.6 Guidance Laws

Any guidance law may be simulated by the program; however, for convenience, some guidance implementations are prepackaged into the program. Thus, at the beginning of the subroutine DER is a list of commented cards containing the following statements:

(a) Pursuit Guidance
(b) PLG Guidance
(c) Sidewinder Guidance (PNG).

These statements head the required changes in the program needed to implement that form of guidance. Thus, for example, implementation of PLG guidance only requires the replacement of the current calculation of YP(5,1) by the one following the card with the statement PLG GUIDANCE.

*Variation in X_{cg} and M during motor burn is assumed proportional to the ratio of the impulse imparted to the total impulse available from the motor.

SECTION IV

PROGRAM DESCRIPTION

4.1 Program Aids

In order to effectively coordiante the variables used in the program with the system equations developed above, Table I is to be used for the identification of the state variables and Table IV will provide definitions for the other variables used by the program. In addition, Figure 3 defines the form in which the input must be prepared and the output format of the program.

A complete listing of the program and its output is given in Appendix I. Appendix II contains the aerodynamic curves for an actual missile. These aerodynamic coefficients are all given as a function of Mach number. Since accurate functional representation of some of these curves are very complex, simple mathematical expressions were chosen which are true only over defined Mach number regimes. The adequacy of the representation may be assessed by the reader by comparing the results obtained from the equations listed in the program with the aerodynamic curves they are intended to represent. These curves are shown in Figure II-1 through Figure II-8.

Input Format

FORMAT (1P6E12.4)

FPT,H,TEN,AR,DVI,VI,DTH,ALP,RANGE,LOS,GBIAS,
VLAZRP,XLASR,DSPEED,TZ

Y(1,1), Y(2,1), Y(3,1), Y(4,1). . . . . . . Y(6,1)

Y(7,1). . . . . .Y(12,1)

Y(13,1), Y(14,1)

Output Format

FORMAT (1P9E12.4)

Y(1,1), YP(1,1), Y(2,1), YP(2,1). . . . . . (5,1)

YP(5,1), Y(6,1) . . . . .YP(9,1)

Y(10,1), YP(10,1) . . . . .YP(13,1), Y(14,1)

YP(14,1)

X,TACC

Figure 3. Input - Output Format.

TABLE IV. PROGRAM NOMENCLATURE

H	Time increment, DT
TEN	Angular orientation of thrust vector
AR	Offset of rocket motor from center line of missile
DVI	Change in missile velocity in feet/second (initial condition)
VI	Initial velocity of missile
DTH	Increment in the line of sight (for next run)
ALP	Angle of attack (in degrees)
RANGE	Range of target along line of sight (feet)
LOS	Line of sight, angle in degrees (always positive)
GBIAS	Gravity bias term
FPT	Number of time increments not to be exceeded
X	Current time, initial time
TIM	Time of next laser pulse
THF	Thrust factor (not implemented)
MAC	Mach No.
ES	Surface area
XCP	Location of c.g. in missile diameters
D	Missile diameter
TACC	Total acceleration magnitude
AL	Angle of attack α

TABLE IV. (CONCLUDED)

IXX	Moment of inertia in X direction
IYY	Moment of inertia in Y direction
IZZ	Moment of inertia in Z direction
CA	Drag coefficient
DCA	Induced drag
CND	Control vane normal force
CNA	Body normal force
CMD	Tail misalignment coefficient
XCP	CP location - diameters from nose
CMT	Pitch damping coefficient
IC	Total number of increments of initial condition DTH
IK	Printout occurs every IKth increment of H
N	Number of state variables
XLASR	Standard deviation of laser spot in X direction
VLAZRP	Percent of time laser pulse acquired by seeker/100 (used in pulse loss logic)
TZ	Length of time for which seeker is caged (pursuit guidance)
TACC	Total accleration of missile
DSPEED	Counter (if greater than one, aircraft speed is incremented by DV1 for next launch
DTH	Increment by which initial orientation is changed for next launch

APPENDIX I

PROGRAM LISTING

```
      EP=0.
      COMMON/VAR/TEN,AR,TIM,THF,TTK,TACC,GBIAS
     *,YFL,VLAZRP,XLASR
     *,EP,FS,ER,TZ
      DIMENSIONY(14,6),YP(14,6),V(14)
      EXTERNALDER
      REALLOS
    1 CONTINUE
      X=0.
      TIM=0.
      IC=10
      IT=0
      IK=8
      N=14
       READ(5,900)FPT,H,TEN,AR,DV1,V1,DTH,ALP,RANGE,LOS,GBIAS
     *,VLAZRP,XLASR
     *,DSPEED,TZ
           WRITE(6,900)FPT,H,TEN,AR,DV1,V1,DTH,ALP,RANGE,LOS,GBIAS
     *,VLAZRP,XLASR
     *,DSPEED,TZ
  900 FORMAT(1P6E12.4)
      MPT=FPT
      DTH=DTH/57.6
      DO4I=1,14
    4 Y(I,1)=0.
      Y(12,1)=1000.
      BBC=IC/2*DTH
    2 CONTINUE
      V1=V1+DV1
      PV=LOS/57.6
      Y(1,1)=-RANGE*COS(PV)
      Y(3,1)=-RANGE*SIN(PV)
      Y(6,1)=PV
      Y(5,1)=Y(6,1)
      Y(10,1)=-Y(6,1)+BBC
      BBC=0.
      PT=-Y(10,1)+ALP/57.6
      Y(2,1)=V1*COS(PT)
      Y(4,1)=V1*SIN(PT)
      FS=0.
      ER=0.
      EP=0.
      WRITE(6,920)(Y(K,1),K=1,N)
      DO5I=1,14
    5 V(I)=Y(I,1)
    6 CONTINUE
      CALLMCCAMS(X,H,MPT,N,Y,YP,DER,IK)
      X=0.
      TIM=0.
      IF(DSPEED.GT.1.)GOTO2
      IT=IT+1
      DO10I=1,14
   10 Y(I,1)=V(I)
      Y(10,1)=Y(10,1)-DTH*IT
      Y(5,1)=-Y(10,1)
      Y(5,1)=-Y(10,1)
      IF(TZ.GT.0.)GOTO12
      Y(5,1)=Y(6,1)
   12 CONTINUE
      V2=V1
      Y(2,1)=V2*COS(Y(10,1))
      Y(4,1)=-V2*SIN(Y(10,1))
      EP=0.
```

```
      FS=0.
      ER=0.
      TIM=0.
      WRITE(6,900)FPT,H,TEN,AR,OV1,V1,OTH,ALP,RANGE,LOS,GBIAS
     *,VLAZRP,XLASR
      WRITE(6,920)(Y(K,1),K=1,N)
      IF(IC-IT)15,15,6
   15 CONTINUE
  920 FORMAT(1P6E12.4)
   20 STOP
      END
      SUBROUTINEDER(X,N,Y,YP,H,LZ,LY)
      DIMENSIONY(14,6),YP(14,6)
      COMMON/VAR/TEN,AR,TIM,THF,TTK,TACC,GBIAS
     *,YFL,VLAZRP,XLASR
     *,EP,FS,ER,TZ
      REALMAS,IXX,IYY,IZZ,MAC
C     PLC GUIDANCE
C      YP(5,1)=-(EP+FS)/A4
C     PURSUIT GUIDANCE
C     YP(5,1)=-EP
C     SIDE WINDER GUIDANCE
C     A8=20.*6.28318
C    1+YP(10,1))*A8**2
C     C2=10./PI
C     C3=.001/PI
C     C4=1./PI
C     PI=57.295776
C     YP(5,1)=-EP+C2*(ER-FS)+C3*FS
C     YP(9,1)=0.
C     YP(8,1)=-2.*A7*A8*Y(8,1)-A8**2*Y(7,1)+C4*(YP(5,1)
      RANGE=SQRT(Y(1,1)**2+Y(3,1)**2)
      TC=.25
      TF=1.3
      TZ=0.
      TR=.8
      RH=.072/32.2
      V1=(Y(2,1)**2+Y(4,1)**2)**.5
      C=.5*RH*V1*V1
      AL=(Y(2,1)*SIN(Y(10,1))+Y(4,1)*COS(Y(10,1)))/(Y(2,1)*COS(Y(10,1)
     1)-Y(4,1)*SIN(Y(10,1)))
      IF(AL.EQ.0.)GOTO42
      BL=ABS(AL)
      AL=AL/BL*ATAN(BL)
   42 CONTINUE
      D=.416
      XC=8.4*C
      ES=.136
      TTOT=7500.*.8+3750.*(TF-TR)
      Y(7,1)=Y(7,1)+GBIAS*1.5/57.6
      P1=12./57.6
      P1=24./57.6
      PP=ABS(Y(7,1))
      IF(PP-P1)4,4,3
    3 Y(7,1)=Y(7,1)/PP*P1
    4 CONTINUE
      IF(X.GT.TR)GOTO30
      TH=7500.
      TTC=7500.*X
      TTC=TTC/TTOT
      GOTO33
   30 IF(X-TF)31,31,32
```

```
32  TH=0.
    TTC=1.
    GOTO33
31  TH=7500.*(TF-X)/(TF-TR)
    TTC=(TTCT-TH*(TF-X)*.5)/TTOT
33  TTC=1.-TTO
    XCG=(8.75+(10.6-8.75)*TTO)*D
    MAS=(3.48+(4.21-3.48)*TTO)
    IXX=(.0686+(.0914-.0686)*TTO)
    IYY=25.04+(29.56-25.04)*TTO
    IZZ=IYY
    MAC=V1/1150.
    IF(MAC.GE.2.)MAC=2.
    IF(MAC.GT..75)GOTO10
    CA=.4
    GOTO12
10  IF(MAC.GT.1.2)GOTO11
    CA=(MAC-.56)*.6/.24
    GOTO12
11  CA=1.44-MAC*.22/2.8
12  IF(TH.EQ.0.)GOTO13
    CA=.93*CA
13  CONTINUE
    IF(MAC.GT..92)GOTO16
    DCA=(.25*MAC**3+.63)*(ABS(Y(7,1)*2.88))**2.2
    GOTO17
16  DCA=(-(MAC-2.8)**3*.0375+(MAC-2.8)*.12+.4)*(ABS(Y(7,1))*2.88)**
   12.1
17  CONTINUE
    CND=3.9-COS(MAC*3.14159/2.8)*.7
    IF(MAC.GT..75)GOTO18
    CNA=15.8
    GOTO21
18  IF(MAC.GT.1.)GOTO19
    CNA=15.8+9.2/.36*(MAC-.75)
    GOTO21
19  IF(MAC.GT.1.5)GOTO20
    CNA=21.3
    GOTO21
20  CNA=(MAC-2.8)**2*.71+20.1
21  IF(MAC.GT.1.)GOTO23
    CMC=(MAC)**3.5*10.3+4.3
    GOTO24
23  CMC=EXP(-MAC+1.)*14.6+(MAC-1.)*4./1.8
24  XCP=(-(MAC-.6)**2*.632+14.02+(MAC-.6)**4*.102)*.416
    IF(MAC.GT.1.4)GOTO26
    CMT=MAC**2*850.+3700.
    GOTO28
26  CMT=EXP(-MAC+1.4)*5600.+(MAC-1.4)*2150.
28  CONTINUE
    F1=-(CA+2.*DCA*ABS(Y(7,1)))*Q*ES+TH
    F3=-(CNA*AL+CND*Y(7,1))*Q*ES+TH*SIN(TEN)
    A1=10.
    A2=.08
    A3=10.
    A4=4.
    A5=2./57.6
    A6=TC
    A7=.5
    A8=80.
    A8=20.
    A9=1.
```

```
      B1=-(1.+2.*A7*A8*A2)/A2
      B2=-(A8**2*A2+2.*A7*A8)/A2
      B3=-A8**2/A2
      B4=-A8**2*A3*A9
      B5=B4/A2
      B6=B4*A1
      YP(1,1)=Y(2,1)
      YP(3,1)=Y(4,1)
      YP(7,1)=Y(8,1)
      YP(8,1)=Y(9,1)
      YP(10,1)=Y(11,1)
      Z2=Z2-.1
      Z2=TIM+.1-X
      IF(Z2.GT.0.)GOTO7
      TIM=X
      ZK3=((1.+200./RANGE)*6.)
      IF(ZK3.GT.15.)GOTO7
      EP=Y(10,1)
      SZT=0.
      AAA=0.
      CALL GAUSS(SZT,AAA,AAV,X)
      IF(YFL.GT.VLAZRP)GOTO7
      SST=C.
      SSX=XLASR*SIN(Y(6,1))/RANGE
      CALL GAUSS(SSX,SST,SSXV,X)
      FS=-SSXV/RANGE+Y(5,1)
      ER=Y(6,1)
 7    CONTINUE
      IF(TZ-X)80,81,81
 81   FS=-EP
      YP(5,1)=0.
      GOTO85
 80   YP(5,1)=-(EP+FS)/A4
 85   CONTINUE
      YP(6,1)=1./(Y(1,1)**2+Y(3,1)**2)*(Y(1,1)*Y(4,1)-Y(3,1)
     1*Y(2,1))
      YP(9,1)=B1*Y(9,1)+B2*Y(8,1)+B3*Y(7,1)+B5*(ER-FS)+B6*( YP(5,1))
      YP(11,1)=-CMT*Y(11,1)*(RH*V1/4.)*ES*D**2/IYY+Q*ES*D/IYY*(-CNA*(XCP
     1-XCG)*AL+CND*(XCG-XC)*Y(7,1))-TH*AR/IYY
      IF(ABS(YP(9,1)).GT. 1000.)YP(9,1)=SIGN( 1000.,YP(9,1))
      YP(2,1)=(F1*COS(Y(10,1))+F3*SIN(Y(10,1)))/MAS
      YP(4,1)=(-F1*SIN(Y(10,1))+F3*COS(Y(10,1)))/MAS+32.2
      AA=10.
      YP(12,1)=-V1*COS(Y(13,1)-Y(14,1))
      YP(13,1)=V1*SIN(Y(13,1)-Y(14,1))/Y(12,1)
      YP(14,1)=AA*YP(13,1)
      IF(X-TC)40,50,50
 40   YP(9,1)=0.
      YP(8,1)=0.
      YP(7,1)=0.
      YP(14,1)=0.
      YP(13,1)=0.
      YP(12,1)=0.
      GOTO70
 50   IF(X-TC-H)60,60,70
 60   Y(13,1)=3.14159625/2.-Y(6,1)
      Y(14,1)=3.14159625/2.+Y(10,1)-AL
      Y(12,1)=(Y(1,1)**2+Y(3,1)**2)**.5
      YP(12,1)=-V1*COS(Y(13,1)-Y(14,1))
      YP(13,1)=V1*SIN(Y(13,1)-Y(14,1))/Y(12,1)
      YP(14,1)=AA*YP(13,1)
 70   CONTINUE
```

```
      TACC=SQRT(YP(2,1)**2+YP(4,1)**2)
      RETURN
      END
      SUBROUTINEMCCAMS(X,H,MPT,N,U,F,DER,IK)
      DIMENSIONU(14,6),F(14,6)
      COMMON/VAR/TEN,AR,TIM,THF,TTK,TACC,GBIAS
     *,YFL,VLAZRP,XLASR
     *,EF,FS,ER,TZ
      DATA PREC1, PREC2, PREC3, PREC4
     .    /55.0, -59.0, 37.0, -9.0/
     .    ,CORR1, CORR2, CORR3, CORR4
     .    /9.0, 19.0, -5.0, 1.0/
          H24 = H / 24.0
          P1 = PREC1 * H24
      P2 = PREC2 * H24
      P3 = PREC3 * H24
          P4 = PREC4 * H24
          C1 = CORR1 * H24
      C2 = CORR2 * H24
      C3 = CORR3 * H24
          C4 = CORR4 * H24
      DATA ALPHA2, ALPHA3
     .    /.4, .45573725/
     .    ,BETA21, BETA31, BETA32, BETA41, BETA42, BETA43
     .    /.4, .29697761, .15875964, .2181004,-3.05096516, 3.83286476/
     .    ,OMEGA1, OMEGA2, OMEGA3, OMEGA4
     .    /.17476028,-.55148066, 1.2055356, .17118478/
      CALLDER(X,N,U(1,1),F(1,1),H,1,1)
        IF (MPT .LE. 1 ) RETURN
          A2 = ALPHA2 * H
      A3 = ALPHA3 * H
          B21 = BETA21 * H
      B31 = BETA31 * H
      B32 = BETA32 * H
          B41 = BETA41 * H
      B42 = BETA42 * H
      B43 = BETA43 * H
          O1 = OMEGA1 * H
      O2 = OMEGA2 * H
      O3 = OMEGA3 * H
          O4 = OMEGA4 * H
          LL = MINO (3,MPT-1)
      DO 10 K = 1,LL
      DO 1 I = 1,N
          U(I,5) = U(I,K) + B21 * F(I,K)
    1 CONTINUE
          A = X + A2
      CALLDER(A,N,U(1,5),F(1,5),H,5,5)
      DO 2 I = 1,N
          U(I,5) = U(I,K) + B31 * F(I,K) + B32 *F(I,5)
    2 CONTINUE
          A = X + A3
      CALLDER(A,N,U(1,5),F(1,6),H,5,6)
      DO 3 I = 1,N
          U(I,5) = U(I,K) + B41 * F(I,K) + B42 * F(I,5) + B43 * F(I,6)
    3 CONTINUE
          X = X + H
      CALLDER(X,N,U(1,5),U(1,6),H,5,6)
      DO 4 I = 1,N
          U(I,K+1) = U(I,K) + O1 * F(I,K) + O2 * F(I,5)
     .                      + O3 * F(I,6) + O4 * U(I,6)
    4 CONTINUE
```

```
      LC=K+1
      CALLCER(X,N,U(1,K+1),F(1,K+1),H,LO,LD)
   10 CCNTINUE                                                         MDM00610
        IF (MPT .LT. 5) RETURN                                         MDM00620
      K=5
      KT=0
      JK=IK
      CC40LK=5,MPT
      CC 20 J = 1,N
          U(J,K) = U(J,K-1) + P1 * F(J,K-1) + P2 * F(J,K-2)           MDM00660
     .                       + P3 * F(J,K-3) + P4 * F(J,K-4)           MDM00670
   20 CCNTINUE                                                         MDM00680
      X = X + H
      CALLCER(X,N,U(1,K),F(1,K),H,K,K)
      DC 30 J = 1,N                                                    MDM00700
          U(J,K) = U(J,K-1) + C1 * F(J,K) + C2 * F(J,K-1)             MDM00710
     .                       + C3 * F(J,K-2) + C4 * F(J,K-3)           MDM00720
   30 CCNTINUE                                                         MDM00730
      CALLDER(X,N,U(1,K),F(1,K),H,K,K)
      IF(K-6)32,33,33
   32 K=6
      GCTC37
   33 DC34IT=1,5
      DC34JT=1,N
      U(JT,IT)=U(JT,IT+1)
   34 F(JT,IT)=F(JT,IT+1)
   37 IF(JK-6)36,36,39
   42 JK=JK+IK
   36 WRITE(6,11)((U(JJ,JK),F(JJ,JK)),JJ=1,N)
      WRITE(6,11)X,TACC
      IF(JK+IK-6)42,42,43
   43 JK=JK+IK
   39 JK=JK-1
      IF(L(3,5))40,40,12
   40 CCNTINUE                                                         MDM00750
   12 CCNTINUE
      JK=JK-IK+1
      WRITE(6,11)((U(JJ,JK),F(JJ,JK)),JJ=1,N)
      WRITE(6,11)X,TACC
   11 FCRMAT(1X,1P9E12.4)
                          RETURN                                       MDM00760
                          END                                          MDM00770
      SUBRCUTINEGAUSS(S,AM,V,T)
      CCMMCN/VAR/TEN,AR,TIM,THF,TTK,TACC,GBIAS
     .,YFL,VLAZRP,XLASR
     .,EF,FS,ER,TZ
      CATA   (K = 37777777777778)
      CATA   (E=777777777777700CCCCC08)
C     S-THE RECUIRED STANCARC DEVIATION
C     AM-IS THE RECUIRED MEAN
C     V-VALUECF CCMPUTEC NORMALLY DISTRIBUTED RANDOM NUMBER
      IF(T.GT.0.)GOTO4
    2 IF(IX)7,8,8
    7 IX=-IX
    8 IF(IX.GT.999      )GOTO3
      IX=IX*2+1
      A=0.
      GCTC4
    3 IX=IX/10
      GCTC2
    4 CC50I=1,12
      IF(I.GT.1)IX=IY
```

```
      J=IX*262147
      IX=J.AND.K
      IZ=IX.AND.J
      B=FLOAT(IZ)/3.4359739E10
      YFL=B.AND.E
      IX=IY
   50 A=A+YFL
      V=(A-6.)*S+AM
      RETURN
      END
7
   1.0000E+03  2.0000E-02  0.0000E+00  0.0000E+00  0.0000E+00  5.0000E+02
   2.5000E+00  0.0000E+00  8.3500E+03  9.7500E+00  2.5000E-01  8.0000E-01
   2.5000E+00  0.0000E+00  0.0000E+00
7
7
```

```
 1.0000E 03  0.0          1.0000E-02  0.0          0.0          0.0
 4.3403E-02  8.0000E-01
-7.0000E 03  3.4739E 02 -1.0000E 04  9.1451E 02  8.7326E-01  9.4007E-01
 0.0         0.0         0.0        -8.7326E-01  0.0          1.0000E 03
 0.0         0.0
-6.9775E 03  4.0242E 02  4.0242E 02  9.2147E 02 -9.9731E 03  4.3208E 02  4.8200E 02  1.1311E 03  8.7326E-01
 0.0         9.5332E-01  4.3851E-03  0.0         0.0         0.0         0.0         0.0         0.0
-8.7328E-01 -1.0651E-03 -1.0651E-03 -3.7002E-02  1.0000E 03  0.0         0.0         0.0         0.0
 0.0
 5.0000E-02  1.4533E 03
-6.9423E 03  4.7657E 02  4.7659E 02  9.3275E 02 -9.9106E 03  5.7308E 02  5.7306E 02  1.1440E 03  8.7327E-01
 3.3465E-05  9.6075E-01  5.1383E-03  0.0         0.0         0.0         0.0         0.0         0.0
-8.7355E-01 -6.3054E-03 -6.3054E-03 -9.4219E-02  1.0000E 03  0.0         0.0         0.0         0.0
 0.0
 1.4000E-01  1.4761E 03
-6.9011E 03  5.5163E 02  5.5163E 02  9.4202E 02 -9.8312E 03  6.6513E 02  6.6513E 02  1.1561E 03  8.7327E-01
 2.8506E-04  9.5114E-01  5.9246E-03  0.0         0.0         0.0         0.0         0.0         0.0
-8.7441E-01 -1.5609E-02 -1.5609E-02 -1.3389E-01  1.0000E 03  0.0         0.0         0.0         0.0
 0.0
 2.2000E-01  1.4713E 03
-6.8539E 03  6.2710E 02  6.2710E 02  9.4099E 02 -9.8243E 03  7.5796E 02  7.5796E 02  1.1670E 03  8.7329E-01
 2.8502E-04  9.6161E-01  6.7305E-03 -4.4479E-02 -2.5906E 00 -2.5906E 00 -8.1319E 01 -8.1739E 01  1.6767E 02
-8.7619E-01 -3.1192E-02 -3.1192E-02 -3.9482E-01  1.1976E 04 -9.8060E 02  6.0215E-01 -6.5641E-03  6.8916E-01
-6.5641E-02
 3.0000E-01  1.4791E 03
-6.8302E 03  7.0100E 02  7.0100E 02  9.1156E 02 -9.7573E 03  8.5243E 02  8.5243E 02  1.1913E 03  8.7335E-01
 1.6135E-03  9.5221E-01  7.3812E-03 -2.0833E-01 -5.9957E 00 -5.9957E 00 -1.6646E 00 -1.6646E 00  6.2622E 02
-8.8146E-01 -1.1244E-01 -1.1244E-01 -1.1514E 00  1.1994E 04 -1.1005E 03  6.0851E-01 -6.9646E-03  6.8374E-01
-6.9646E-02
 3.8000E-01  1.5003E 03
-6.7417E 03  7.7282E 02  7.7282E 02  8.8107E 02 -9.6977E 03  9.6648E 02  9.6148E 02  1.2109E 03  8.7351E-01
 9.1436E-03  9.6292E-01  7.8422E-03 -2.0333E-01 -5.3419E 00 -5.3419E 00  9.5293E 00  9.5293E 00 -9.2661E 01
-8.9436E-01 -1.7299E-01 -1.7299E-01 -2.5375E-01  1.1901E 04 -1.2205E 03  6.0804E-01 -7.2515E-03  6.7804E-01
-7.2515E-02
 4.6000E-01  1.4974E 03
-6.5771E 03  8.4104E 02  8.4104E 02  8.4002E 02 -9.6079E 03  1.0461E 03  1.0461E 03  1.2287E 03  8.7394E-01
 4.1165E-03  9.6345E-01  8.0483E-03 -2.0433E-01 -4.9512E 00 -4.9512E 00  8.5331E-01  8.5331E-01 -6.4618E 01
-9.0575E-01 -1.4647E-01 -1.4647E-01  8.6580E-01  1.1697E 04 -1.3399E 03  6.0745E-01 -7.4221E-03  6.7216E-01
-7.4221E-02
 5.4000E-01  1.4904E 03
-6.6073E 03  9.0821E 02  9.0321E 02  8.2507E 02 -9.5202E 03  1.1458E 03  1.1458E 03  1.2600E 03  8.7450E-01
 3.5717E-03  9.6310E-01  8.0131E-03 -2.0433E-01 -4.8172E 00 -4.8172E 00  1.6488E 00  1.6488E 00 -2.2394E 01
-9.1307E-01 -5.8045E-02 -5.8045E-02  1.1246E 00  1.1587E 04 -1.4595E 03  6.0685E-01 -7.4839E-03  6.6619E-01
-7.4839E-02
 6.2000E-01  1.5061E 03
-6.5317E 03  9.7390E 02  9.7390E 02  8.1979E 02 -9.4244E 03  1.2471E 03  1.2471E 03  1.2692E 03  8.7527E-01
 1.0432E-02  9.6471E-01  7.8570E-03 -2.0833E-01 -4.7058E 00 -4.7058E 00  1.4909E 00  1.4909E 00 -9.2034E 00
-9.1691E-01 -1.2316E-03 -1.2316E-03  1.4627E-01  1.1465E 04 -1.5960E 03  6.0625E-01 -7.4934E-03  6.6022E-01
-7.4934E-02
 7.0000E-01  1.5104E 03
-6.4511E 03  1.0313E 03  1.0313E 03  8.1454E 02 -9.3205E 03  1.3498E 03  1.3498E 03  1.2754E 03  8.7610E-01
 1.0375E-02  9.6533E-01  7.6697E-03 -2.0833E-01 -4.6359E 00 -4.6359E 00  3.5703E-01  3.5703E-01 -4.3285E 00
-9.1763E-01 -3.5669E-02 -3.5669E-02 -8.6763E-01  1.1334E 04 -1.7707E 03  6.0566E-01 -7.3957E-03  6.5431E-01
-7.3957E-02
 7.8000E-01  1.5133E 03
-6.3659E 03  1.1002E 03  1.1002E 03  6.7517E 02 -9.2285E 03  1.4467E 03  1.4467E 03  1.1324E 03  8.7693E-01
 1.0375E-02  9.6[illegible]  7.3614E-03 -2.0833E-01 -4.6235E 00 -4.6235E 00  2.1047E-02  2.1047E-02 -2.2558E 00
-9.2101E-01 -1.2231E-01 -1.2231E-01 -5.6559E-01  1.1193E 04 -1.8159E 03  6.0508E-01 -7.0560E-03  6.4855E-01
-7.0560E-02
 8.6000E-01  1.5100E 03
```

-6.2753E 03	1.1463E 03	1.1455E 03	4.8421E 02	-9.0593E 03	1.5294E 03	1.5294E 03	9.3492E 02	9.7788E-01
1.2121E-02	9.6652E-01	6.7493E-03	-2.0833E-01	-4.5426E 00	-4.5426E 00	1.4279E 00	1.4279E 00	-1.4703E 01
-9.[illegible]E-01	-1.0752E-01	-1.0752E-01	3.0401E-01	1.1044E 04	-1.9100E 03	6.[illegible]E-01	6.6055E-03	6.4356E-01
-6.[illegible]E-02								
1.[illegible]E [illegible]	1.0[illegible]E 03							
-6.1[illegible]E 03	1.1779E 03	1.1779E 03	3.0627E 02	-9.9642E 03	1.5959E 03	1.5959E 03	7.2351E 02	8.7594E-01
1.4683E-02	9.6702E-01	5.9473E-03	-2.0833E-01	-4.4310E 00	-4.4310E 00	2.5378E 00	2.5378E 00	8.6457E 00
-9.[illegible]E-01	-6.9216E-02	-6.9216E-02	3.5936E-01	1.0988E 04	-1.9024E 03	6.0402E-01	-6.1735E-03	6.3791E-01
-6.1735E-02								
1.0200E 00	7.8839E 02							
-6.0[illegible]E 03	1.1735E 03	1.1955E 03	1.3567E 02	-8.8343E 03	1.6449E 03	1.6449E 03	5.0085E 02	8.8011E-01
1.6125E-02	9.6745E-01	4.7597E-03	-2.0833E-01	-4.2872E 00	-4.2872E 00	1.1004E 00	1.1004E 00	7.0602E 01
-9.4461E-01	-6.8216E-02	-6.8216E-02	-3.0381E-01	1.0727E 04	-2.0325E 03	6.0355E-01	-5.6169E-03	6.3319E-01
-5.6189E-02								
1.1000E 00	5.1890E 02							
-5.9912E 03	1.1996E 03	1.1996E 03	-3.2178E 01	-8.7013E 03	1.6760E 03	1.6760E 03	2.7706E 02	8.8161E-01
1.6125E-02	9.6778E-01	3.5615E-03	-2.0833E-01	-4.1434E 00	-4.1434E 00	1.1941E 00	1.1941E 00	-2.5904E 01
-9.5124E-01	-9.6954E-02	-9.6954E-02	-2.6439E-01	1.0562E 04	-2.0604E 03	6.0312E-01	-5.0355E-03	6.2893E-01
-5.0355E-02								
1.1200E 00	2.7492E 02							
-5.8954E 03	1.1904E 03	1.1904E 03	-1.9546E 02	-8.5566E 03	1.6892E 03	1.6892E 03	5.2945E 01	8.8280E-01
1.9[illegible]E-02	9.6801E-01	2.2146E-03	-2.0833E-01	-3.9971E 00	-3.9971E 00	2.5932E 00	2.5932E 00	-2.0603E 01
-9.[illegible]E-01	-9.9743E-02	-9.9743E-02	1.5915E-01	1.0398E 04	-2.0565E 03	6.0274E-01	-4.4506E-03	6.2513E-01
-4.4506E-02								
1.2600E 00	2.0347E 02							
-5.8039E 03	1.1697E 03	1.1697E 03	-2.8059E 02	-8.4314E 03	1.6861E 03	1.6861E 03	-7.4854E 01	8.8430E-01
2.0275E-02	9.6813E-01	7.6006E-04	-2.0833E-01	-3.8482E 00	-3.8482E 00	3.2242E 00	3.2242E 00	3.7943E 01
-9.6573E-01	-8.5618E-02	-8.5618E-02	1.1304E-01	1.0233E 04	-2.0517E 03	6.0240E-01	-3.8894E-03	6.2[illegible]E-01
-3.8894E-02								
1.3400E 00	2.9041E 02							
-5.7262E 03	1.1476E 03	1.1476E 03	-2.7330E 02	-8.2967E 03	1.6800E 03	1.6800E 03	-7.6375E 01	8.5592E-01
2.0273E-02	9.6814E-01	-6.7738E-04	-2.0833E-01	-3.6338E 00	-3.6338E 00	1.2365E 00	1.2365E 00	-3.6852E 01
-9.7357E-01	-8.5687E-02	-8.5687E-02	-6.3285E-02	1.0070E 04	-2.0340E 03	6.0211E-01	-3.3901E-03	6.1885E-01
-3.3901E-02								
1.4200E 00	2.8377E 02							
-5.6172E 03	1.1260E 03	1.1260E 03	-2.6774E 02	-8.1625E 03	1.6739E 03	1.6739E 03	-7.6335E 01	9.0708E-01
2.2550E-02	9.6602E-01	-2.1565E-03	-2.0833E-01	-3.4083E 00	-3.4083E 00	2.4973E 00	2.4973E 00	-4.2140E 01
-9.8361E-01	-9.2275E-02	-9.2275E-02	-1.7509E-02	9.9076E 03	-2.0172E 03	6.0166E-01	-2.5523E-03	6.1636E-01
-2.5523E-02								
1.5000E 00	2.7855E 02							
-5.5276E 03	1.1047E 03	1.1047E 03	-2.5307E 02	-8.0298E 03	1.6678E 03	1.6678E 03	-7.6800E 01	8.9053E-01
2.3729E-02	9.6779E-01	-3.6789E-03	-2.0833E-01	-3.2035E 00	-3.2035E 00	3.9276E 00	3.9276E 00	-1.4132E 01
-9.8797E-01	-9.0156E-02	-9.0156E-02	7.2244E-02	9.7469E 03	-2.0003E 03	6.0164E-01	-2.5086E-03	6.1415E-01
-2.5086E-02								
1.5400E 00	2.7405E 02							
-5.4433E 03	1.0839E 03	1.0839E 03	-2.5760E 02	-7.8756E 03	1.6616E 03	1.6616E 03	-7.7280E 01	8.9147E-01
2.5725E-02	9.6743E-01	-5.2388E-03	-2.0833E-01	-2.9869E 00	-2.9869E 00	3.2440E 00	3.2440E 00	9.2745E 01
-9.9[illegible]E-01	-8.5006E-02	-8.5006E-02	3.5764E-02	9.5874E 03	-1.9837E 03	6.0144E-01	-2.2326E-03	6.1223E-01
-2.2326E-02								
1.6600E 00	2.6894E 02							
-5.3[illegible]E 03	1.0635E 03	1.0635E 03	-2.5189E 02	-7.7628E 03	1.6554E 03	1.6554E 03	-7.7215E 01	8.9352E-01
2.5725E-02	9.6675E-01	-6.8328E-03	-2.0833E-01	-2.7058E 00	-2.7058E 00	2.0507E 00	2.0507E 00	-5.1182E 01
-1.0017E 00	-8.5063E-02	-8.5063E-02	-2.6780E-02	9.4293E 03	-1.9675E 03	6.0128E-01	-1.5386E-03	6.1057E-01
-1.5386E-02								
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2.7155E-02	9.6633E-01	-8.4649E-03	-2.0833E-01	-2.4278E 00	-2.4278E 00	1.6302E 00	1.6302E 00	-4.0277E 01
-1.0065E 00	-8.6830E-02	-8.6830E-02	-9.0549E-03	9.2725E 03	-1.9515E 03	6.0113E-01	-1.6315E-03	6.0912E-01
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-9.0907E-01	3.1461E-02	3.1461E-02	-5.6065E-03	1.3777E 03	-1.3135E 03	6.0021E-01	0.0	6.0021E-01
0.0								
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-1.2535E-02	7.3391E-01	-1.7115E-01	2.0833E-01	1.3740E 01	1.3740E 01	1.3694E 01	1.3694E 01	-4.8130E 01
-9.0657E-01	3.1024E-02	3.1024E-02	-5.3845E-03	1.2729E 03	-1.3066E 03	6.0021E-01	0.0	6.0021E-01
0.0								
6.8554E 00	9.5196E 01							
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-1.3141E-02	7.1921E-01	-1.9732E-01	2.0833E-01	1.4508E 01	1.4508E 01	1.2390E 01	1.2380E 01	3.7461E 02
-9.0411E-01	3.0613E-02	3.0613E-02	-4.9187E-03	1.1697E 03	-1.2998E 03	6.0021E-01	0.0	6.0021E-01
0.0								
5.9356E 00	9.2993E 01							
-8.5628E 02	8.0010E 02	8.0010E 02	-1.9933E 01	-7.2448E 02	1.0159E 03	1.0159E 03	-8.8458E 01	9.5540E-01
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-9.0167E-01	3.0225E-02	3.0225E-02	-4.9503E-03	1.0649E 03	-1.2931E 03	6.0021E-01	0.0	6.0021E-01
0.0								
7.0196E 00	9.0070E 01							
-7.7234E 02	7.9853E 02	7.9853E 02	-1.9442E 01	-6.4349E 02	1.0089E 03	1.0089E 03	-8.6382E 01	9.5432E-01
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0.0								
7.0756E 00	8.8543E 01							
-7.2851E 02	7.9699E 02	7.9699E 02	-1.8971E 01	-5.6305E 02	1.0020E 03	1.0020E 03	-8.4379E 01	9.5322E-01
-1.3966E-02	6.5792E-01	-3.3176E-01	2.0833E-01	1.8036E 01	1.8086E 01	2.6653E 01	2.6653E 01	8.4243E 01
-8.9690E-01	2.9417E-02	2.9417E-02	-4.9332E-03	8.5907E 02	-1.2803E 03	6.0021E-01	0.0	6.0021E-01
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-1.4397E-02	6.2937E-01	-4.1070E-01	2.0833E-01	1.9589E 01	1.9589E 01	1.4170E 01	1.4170E 01	1.3754E 03
-8.9456E-01	2.9031E-02	2.9031E-02	-4.7479E-03	7.5689E 02	-1.2742E 03	6.0021E-01	0.0	6.0021E-01
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-8.8997E-01	2.8313E-02	2.8313E-02	-4.3050E-03	5.5197E 02	-1.2623E 03	6.0021E-01	0.0	6.0021E-01
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0.0								
7.4955E 00	7.8753E 01							
-4.1116E 02	7.8942E 02	7.7082E 02	-1.6951E 01	-1.6872E 02	9.7012E 02	9.7012E 02	-7.5375E 01	9.4737E-01
-1.5153E-02	3.4934E-01	-1.1447E 00	2.0833E-01	3.2067E 01	3.2067E 01	2.7336E 01	2.7336E 01	-7.9854E 02
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0.0								
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0.0								
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-6.9755E 03  6.0266E 02  6.0266E 02  1.1744E 03 -9.8745E 03  7.2604E 02  7.2604E 02  1.4336E 03  8.7327E-01
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-9.0364E-01 -1.3715E-01 -1.3715E-01  1.2103E 00  1.1647E 04 -1.5[illegible] 03  6.0712E-01 -8.3182E-02  6.7029E-01
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```

APPENDIX II

AERODYNAMIC CURVES

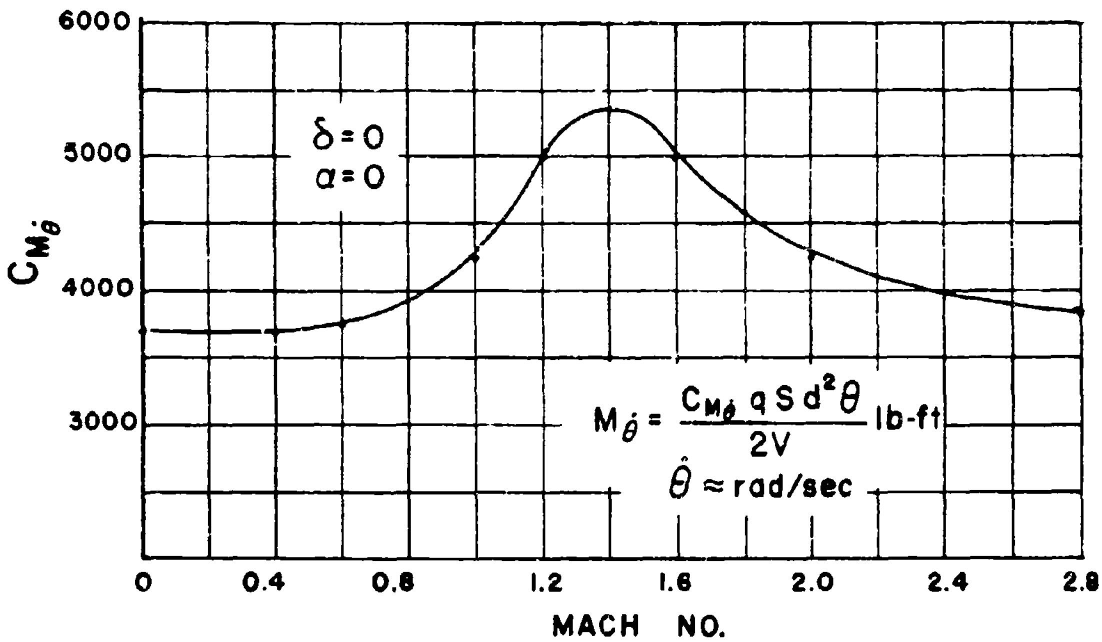

Figure II-1. Aero Pitch Damping Curve

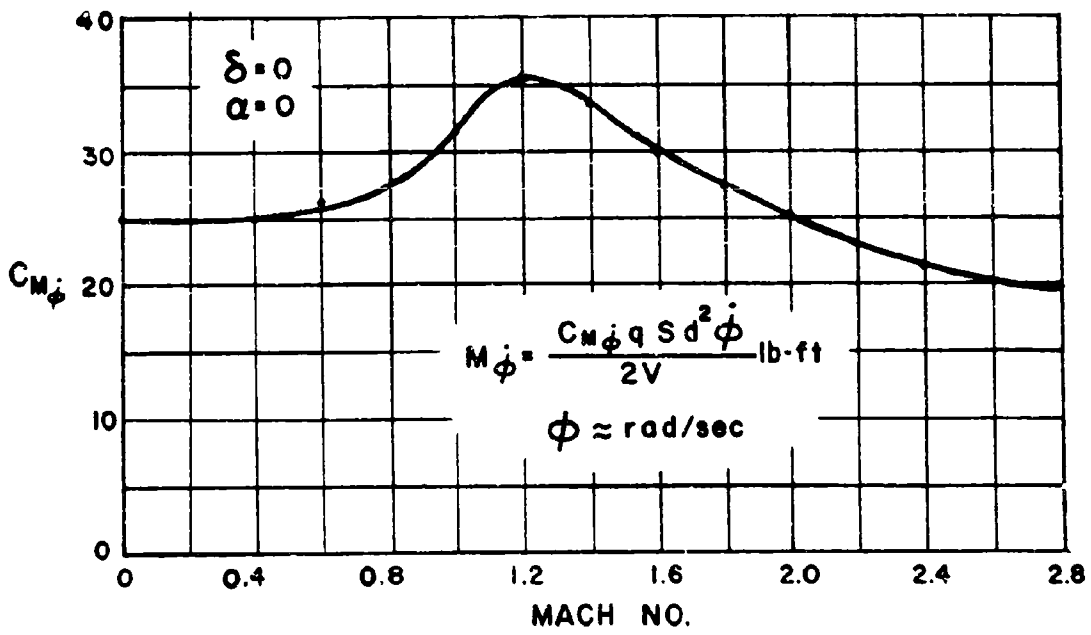

Figure II-2. Aero Roll Damping Curve

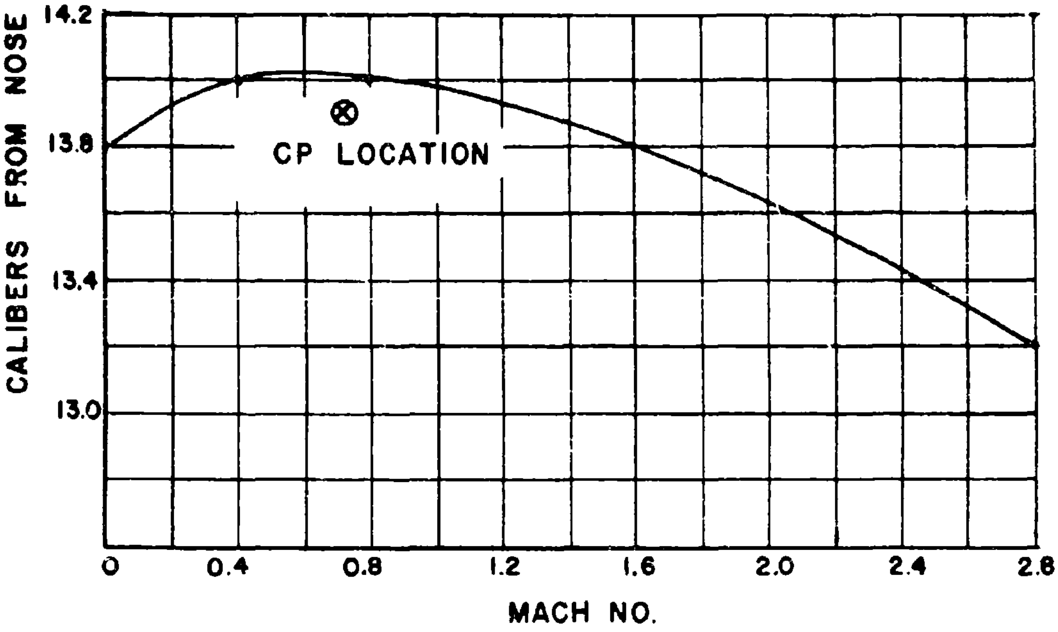

Figure II-3. Center of Pressure Location

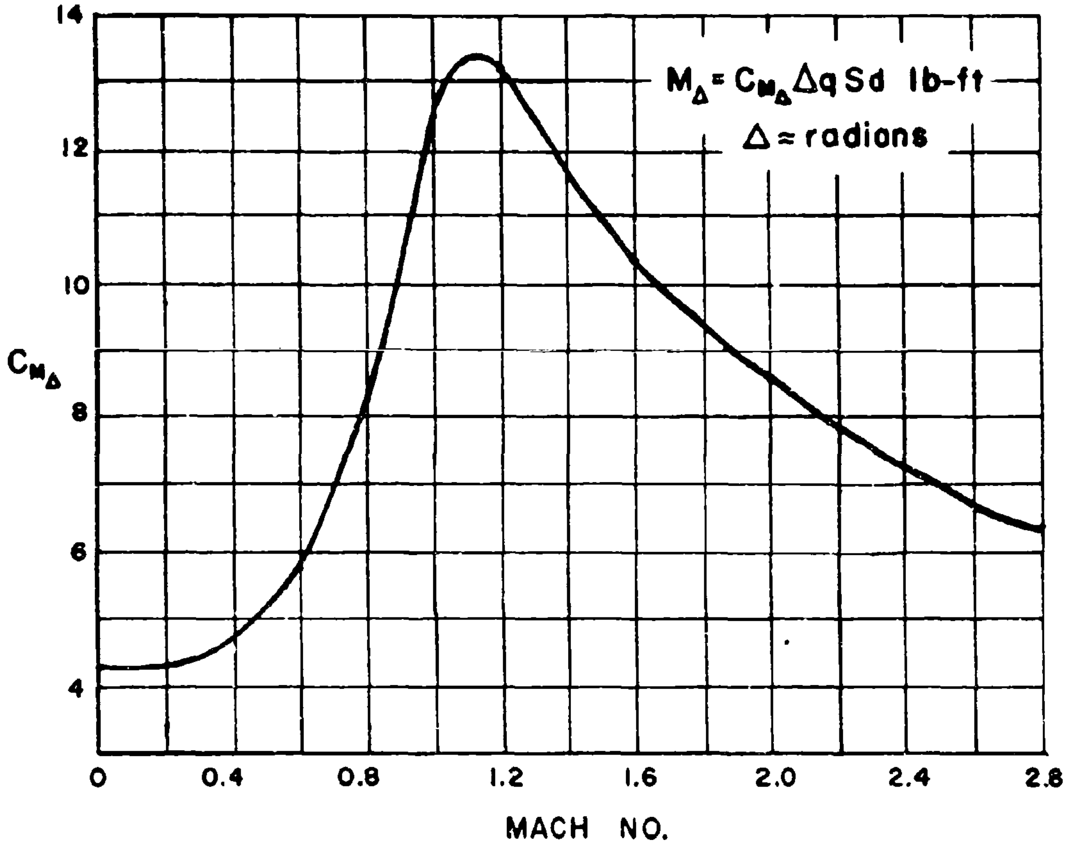

Figure II-4. Tail Misalignment Coefficient

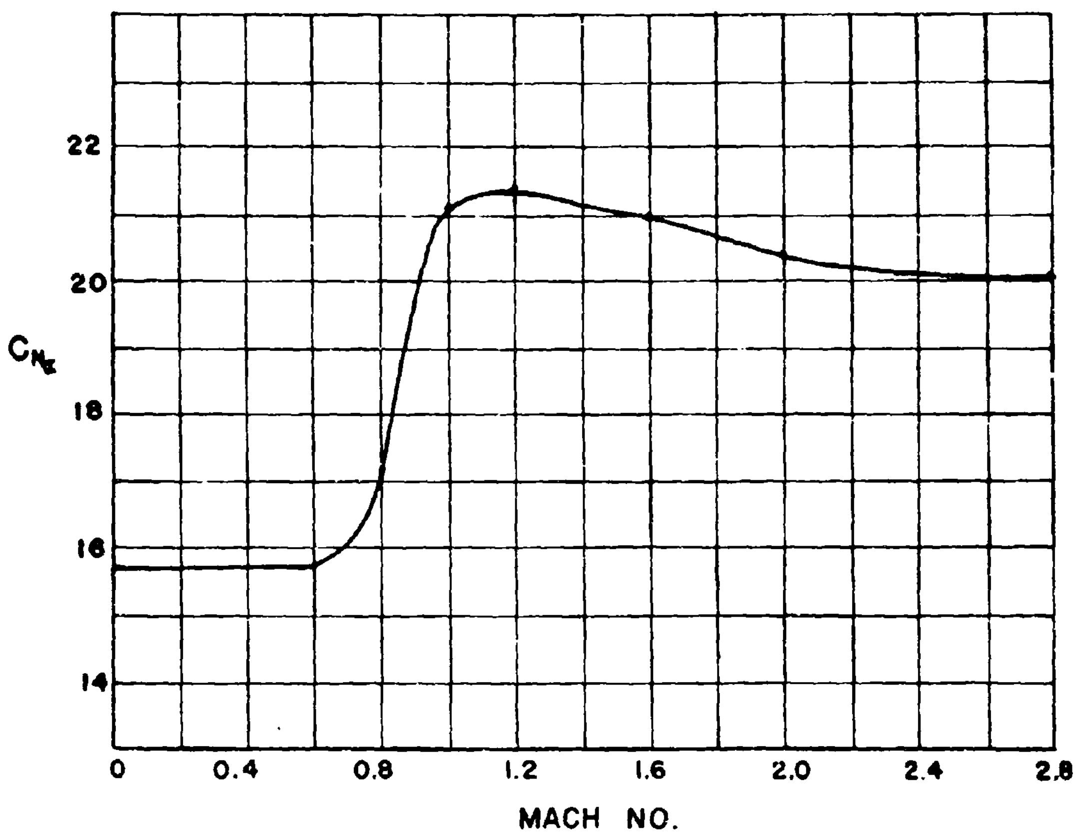

Figure II-5. Body Normal Force

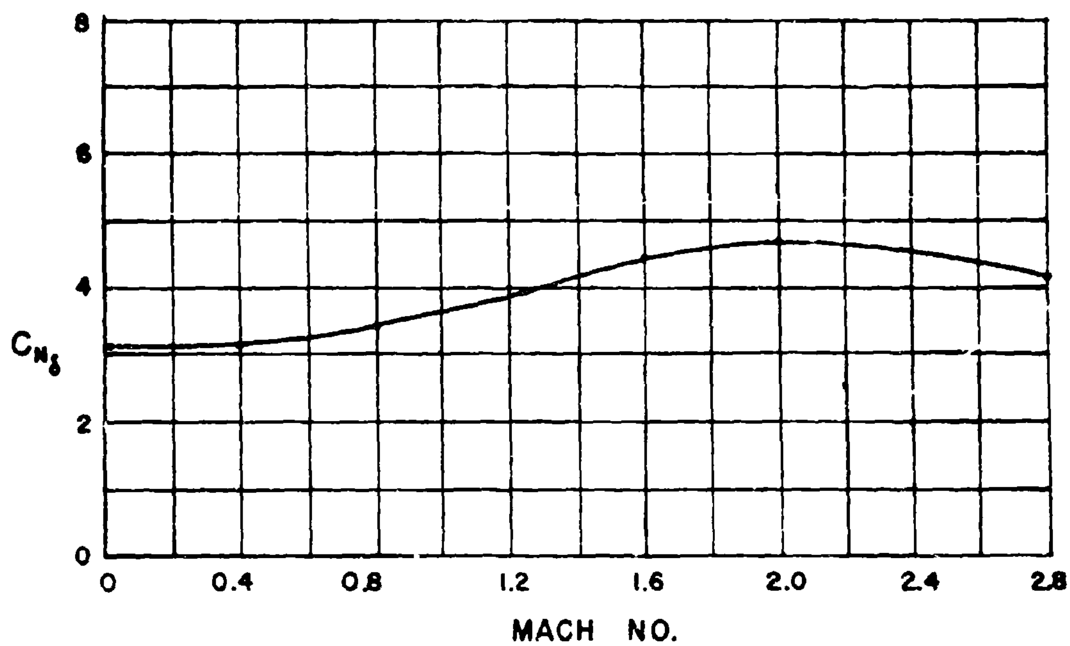

Figure II-6. Control Vane Normal Force

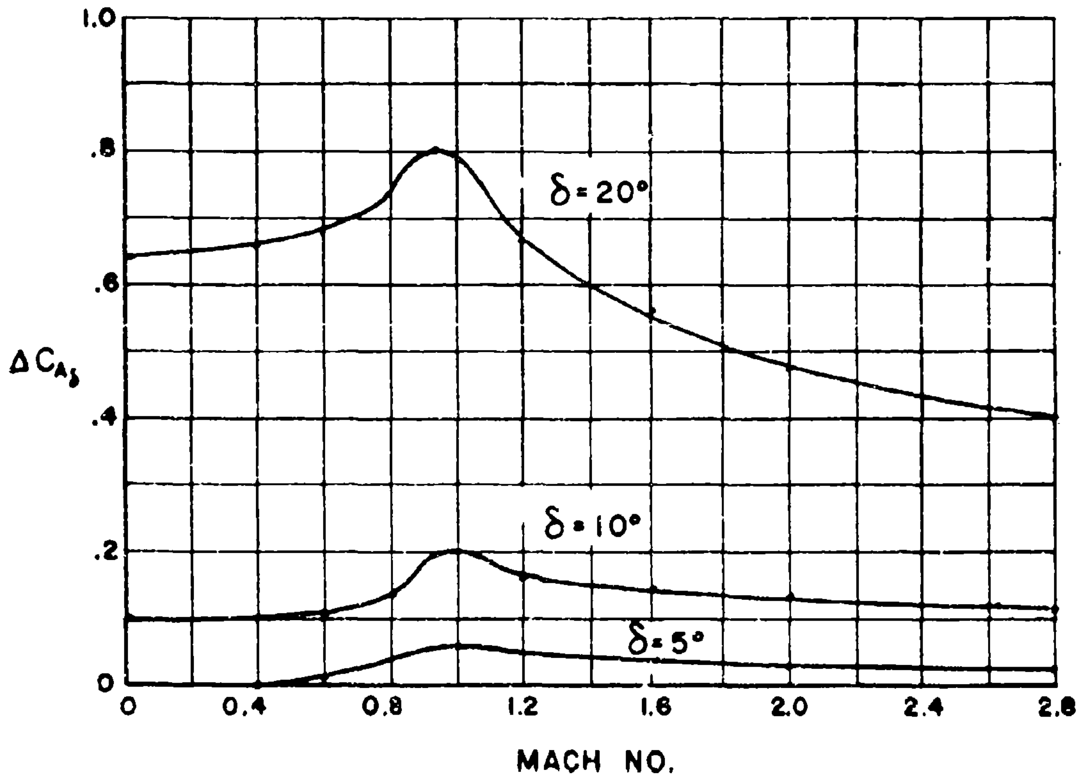

Figure II-7. Induced Drag

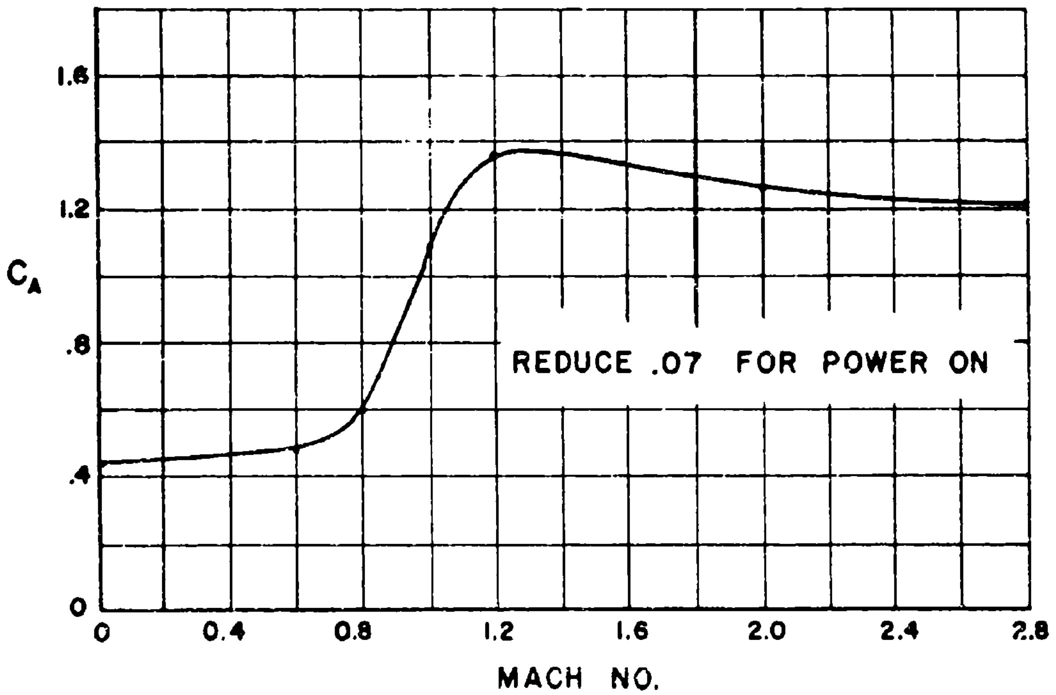

Figure II-8. Drag Force

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13. ABSTRACT

This report describes in detail a three-degree-of-freedom program which can be used to determine the trajectory and miss distance of a guided missile system. The options for the program are such as to permit variation of the aerodynamics, seeker, autopilot, actuator, and missile motor performance for the purpose of accurately simulating a given missile design and evaluating the effects of any changes in system parameters. Sufficient detail has been included in the text to minimize the effort needed to update or modify the program presented.

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Missile Simulation System						
Three-Degree-of-Freedom Simulation						

Security Classification